RADIATION DAMAGE TO MAGNET WATER HOSES AT THE APS*

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Abstract

The Advanced Photon Source (APS) has been operating for seven years. Magnet water hoses at the APS have been exposed to different levels of radiation during this time. This paper presents details of the radiation effects and damage for some of these magnet water hoses as a function of radiation doses.

1. Introduction

There are over 3000 magnet water cooling hoses at the APS. Each of these hoses is exposed to different levels of radiation. This exposure can break down the hose material and shorten the life of a hose. This radiation exposure is the key ingredient to causing early failure of magnet water hoses at the APS. Any hose failure can cause downtime, and any downtime is unacceptable. In the storage ring at the APS, we can comfortably change between sixty to ninety hoses per maintenance period without affecting other maintenance activities. With 1200 hoses in the storage ring alone and only three maintenance periods per year this equates to 4.5 to 7.5 years to replace all hoses in the storage ring. The cost and amount of time to change magnet water hoses in these quantities can be prohibitive. Because of the necessity to avoid downtime associated with changing such a large quantity of hoses, it is necessary to predict when hoses will fail, which hoses will fail first, and to decide when and what hoses to replace first.

2. Description

There are forty sectors in the APS storage ring, and each sector contains several magnets, each with their own cooling hoses. These hoses operate at 0.93 MPa water pressure with the possibility 1.7 MPa intermittent pressure. One of these magnets is a corrector magnet with two water cooling hoses (one supply and one return) that are near x-ray absorbers. These hoses are exposed primarily to scattered x-ray radiation from these absorbers. Each of these hoses is between 1 and 1.4 m long. There are forty of each of these hoses in the APS storage ring. Each hose has one end closer to the radiation source that receives a higher dose of radiation than does the other end. This paper will focus mostly on these two hoses.

These hose assemblies are made of Parker Hannifin Corporation [1] 518B-6 medium-pressure nonconductive hose (aqua color) with Parker 55 series 304 stainless-steel permanent fittings. The hose is constructed with an elastomeric core, fiber reinforcement, and an abrasion-resistant outer jacket. The core material is polybutylene-terephthalate-based copolyester with a proprietary soft segment. The reinforcement material is polyethylene-terephthalate-based polyester yarn. The jacket material is polyurethane with an added proprietary blend.

3. Results

Radiachromic dosimeters were placed on several of these corrector magnet hoses during a normal run between shut-down periods. The dosimeters were placed on the end of the hose that was closest to the radiation source. The radiation dose, during this period, was recorded for each hose. These data were used to approximate the total radiation dose that these hoses were exposed to since they were installed at the start up of the APS. These hoses were removed from the storage ring and burst pressure tested along with a set of six brand new hoses. Radiation doses and corresponding burst pressures along with the type of burst for these hoses are presented in table 1. Hoses 1 through 5 were closest to the radiation source, hoses 6 through 10 were 100 mm further from the radiation source and hoses 11 through 16 are brand new hose assemblies.

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Two different burst types are shown in figure 1. Hose bursts occur when three layers: the core, the fiber reinforcement, and the outer jacket, all fail simultaneously. The cover bubble burst can occur when the core fails and the fluid medium passes through the fiber reinforcement bursting through the outer jacket. The cover bubble burst can also occur when the fluid medium works its way between the core material and the inner tube of the fitting and returns between the core and the outer jacket (through the fiber reinforcement) and ruptures through the outer jacket. The fiber reinforcement remains intact in a cover bubble burst. All hose bursts for hoses 6, 7, 8, and 10 occurred between 150 to 200 mm from the fitting that was closest to the radiation source. All hose bursts for hoses 11 through 16 occurred at least 175 mm away from either fitting. All cover bubble bursts occurred between 20 to 38 mm from the fitting that was nearest to the radiation source. All cover bubble bursts were caused by the core cracking and the fluid medium passing through the fiber reinforcement and bursting through the outer jacket.

Figures 2, 3 and 4 show the color change that occurs after hoses are exposed to x-ray radiation. The red, green, blue (RGB) values in all figures are obtained by taking the average value, inside the corresponding rectangle, using a photo editor. Rectangles were chosen to minimize any glare or light reflection that would distort the RGB color value. Figure 2 shows the color change of the outer jacket. Figure 3 shows the color change in the fiber reinforcement. Figure 4 shows the color change of the core material.

The core material became very brittle and cracked easily when exposed to higher doses of radiation. Figure 4c shows the core material cracked in several places. This cracking occurred while unfolding the hose to take this photograph. Also the adhesive used to bond the hose layers together degraded from radiation exposure. The upper right of figure 4c shows where the outer jacket delaminated from the fiber reinforcement. This delaminating occurred while unfolding the hose to take this photograph. All layers from the sample in figure 4c can easily be pulled apart by hand but the layers from the samples in figure 4a and 4b are strong and cannot be easily pulled apart by hand.

4. Conclusion

The results in table 1 give an indication of how much x-ray radiation reduces the performance of the hoses. Several more data points are required

Table 1: Radiation and burst pressure data.

Hose No.	Radiation Dose	Burst Pressure	Type of burst
	Gray	MPa	
1	1.21E+07	11.24	CBB
2	1.16E+07	11.10	CBB
3	1.41E+07	19.58	CBB
4	1.34E+07	16.07	CBB
5	1.27E+07	10.89	CBB
6	7.88E+05	56.54	HB
7	8.25E+05	59.37	HB
8	8.63E+05	60.81	HB
9	7.50E+05	23.37	CBB
10	8.25E+05	61.30	HB
11	0.00E+00	64.95	HB
12	0.00E+00	64.61	HB
13	0.00E+00	65.43	HB
14	0.00E+00	66.19	HB
15	0.00E+00	66.33	HB
16	0.00E+00	64.12	HB
HB=Hose Burst			
CBB=Cover Bubble Burst			

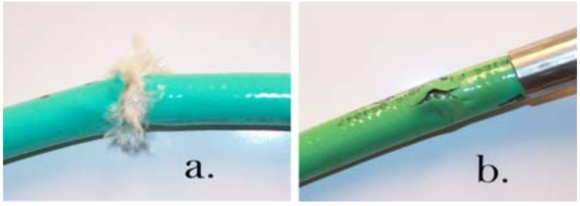

Figure 1: Types of bursts: (a) *hose burst* (b) *cover bubble burst.*

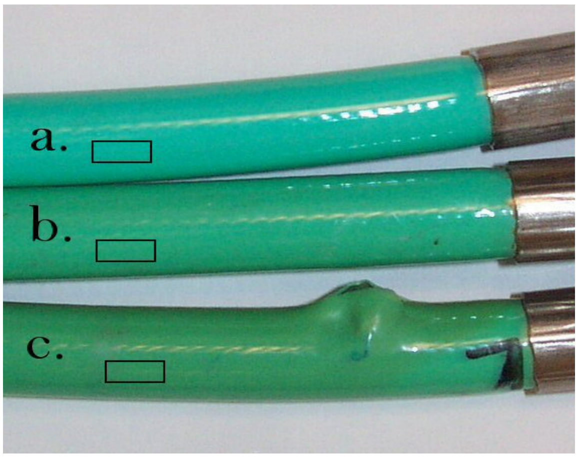

Figure 2: Color change in the outer jacket.
(a) Hose No. 15 (RGB=4, 173, 152).
(b) Hose No. 8 (RGB= 34, 157, 115).
(c) Hose No. 4 (RGB= 50, 139, 92).

to make an accurate burst pressure vs. dose plot. There is a transition of burst type from hose burst to cover bubble burst. It is expected there will be a discontinuous point on a burst pressure vs. dose plot at this transition zone where the burst pressure will drop suddenly.

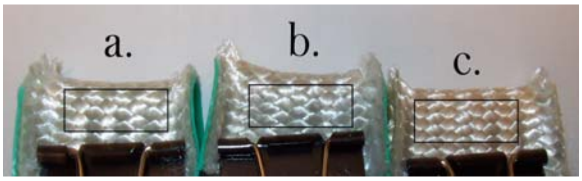

Figure 3: Color change in fiber reinforcement.
(a) Hose No. 15 (RGB=170, 173, 167).
(b) Hose No. 8 (RGB= 153, 162, 161).
(c) Hose No. 4 (RGB= 155, 143, 130).

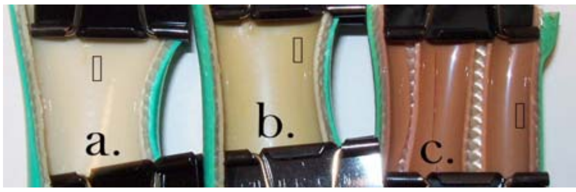

Figure 4: Color change in the core.
(a) Hose No. 15 (RGB= 217, 206, 184).
(b) Hose No. 8 (RGB= 192, 171, 119).
(c) Hose No. 4 (RGB= 139, 88, 65).

The average dose and burst pressure for hoses 1 through 5, from table 1, are 1.28E+07 Gy and 13.8 MPa respectively. Although 13.8 MPa is well within our operating pressure it is not good practice to operate a hose exposed to this dose because the inner core material is very brittle. Any vibration or movement of a hose exposed to this dose of radiation could cause a crack in the hose core and rupture the hose. The average dose and burst pressure for hoses 6 through 10, from table 1, are 8.1E+05 Gy and 52.3 MPa, respectively; 52.3 MPa is well beyond our operating pressure. This would be an acceptable dose at which to operate. The maximum acceptable radiation dose to operate at for our application would be somewhere above 8.1E+05 Gy but below 1.28E+07 Gy.

Color change is a method that could be an indicator of how much radiation exposure the hose has had. For this particular type of hose, the color change appears to be most noticeable in the core material (polybutylene terephthalate based), the fiber reinforcement has the least noticeable color change, while the outer jacket falls somewhere in between. It would be most desirable to monitor the color change in the core, but the core cannot be seen while the hose is installed and operating. It might be worth while to investigate whether hose manufacturers can make a hose with an outer jacket that is highly susceptible to color change when exposed to radiation. Thus the entire hose would be like a dosimeter. Sections of a hose exposed to higher doses of radiation would become darker. This could be compared to a color chart to determine if the hose requires replacement.

5. Acknowledgments

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6. References

[1] Parker Hannifin Corporation, Parflex Division, 1300 North Freedom Street, Ravenna, Ohio 44266